REDUCING INSERTION SITES OF PENETRATING MULTIPOLAR SHAFT ELECTRODES BY DOUBLE SIDE ELECTRODE ARRANGEMENT

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Abstract-**Micromachined devices with substrate-integrated electrodes are the key component in implantable microdevices for recording neuronal signals or stimulating nerves. For basic investigations in central – and partially in peripheral - nerve structures, silicon based shaft electrodes have established as standard multichannel device. In this paper, we present polyimide based multichannel shaft electrodes with a total thickness of 15 µm. The integration of interconnects and an interface to an commercially available connector made additional assembling techniques obsolete. An electrode arrangement on the front side and the back side of the shafts reduces the insertion sites at a given number of electrode channels. Areas on interest in the half planes left and right to the insertion site could be monitored with one device simultaneously. The double side shaft electrodes were inserted in the optic nerve of rats. First recordings were obtained from this acute implantation after visual stimulation of the corresponding eye with flash light.**

***Keywords* - Neural prostheses, polyimide, double-side electrode, micromachining, recording, optical nerve**

I. INTRODUCTION

A major issue in neuroscience and neural rehabilitation is the understanding how the nervous system represents information with bioelectric signals. With the introduction of microsystem technology in the biomedical field, micromachined devices with substrate-integrated electrodes have become the key component in implantable microsystems for recording of neural signals and electrical stimulation of nerves. So far, all biomedical microimplants have a single-sided electrode arrangement. Spatial horizontal resolution could only be obtained by insertion of many needle-like shafts that normally “look” in the same direction for recording and/or stimulation. A double-sided electrode arrangement on microdevices (Fig. 1) could reduce the number of insertion sites and thereby minimize the implantation trauma of neural prostheses. Electrodes “look” in opposite direction and record bioelectric signals from different neurons or populations.

During the last years, flexible, polyimide-based devices with single side electrodes have been developed for several applications to interface parts of the nervous system [1]. The implantation of polyimide sieve electrodes in transected peripheral nerves resulted in excellent regeneration with the ability of nerve signal recording and stimulation [2].

Polyimide-based microdevices have been also used to record neural signals with an intracortical electrode array [3]. From a medical point of view, biostability, toxicity and mechanical interaction of the devices with the surrounding tissue point to an outstanding biocompatibility when properly designed to each application.

Envisioning miniaturized systems with flexible electrode arrangements in polyimide technology [4] for implantation in the brain, double-sided electrode arrangements might be a key component. The number of insertion sites could be halved at a fixed spatial resolution or the spatial resolution could be doubled with the same number of insertion sites. Within this paper, the design of 20 channel shaft electrodes with double-sided electrode arrangements and first recordings from the rat optic nerve were presented.

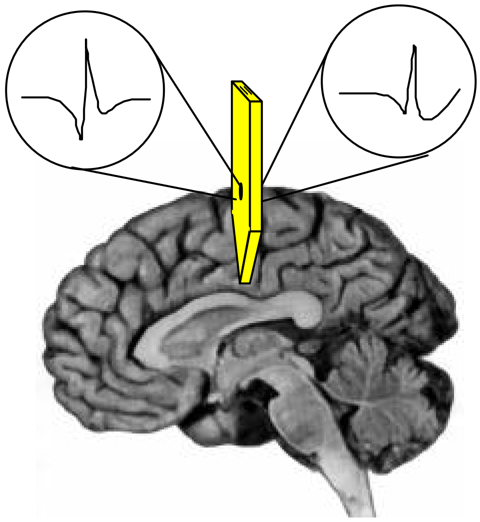

Fig. 1. Schematic view of an implanted double-sided shaft electorde in recording mode.

II. METHODOLOGY

A. Process Technology

A process for single or multilayer metallization that has been sandwiched between layers of polyimide [1] has been further developed towards double-sided electrode arrangements [3]. The objective has been to use as long as possible the processing from one side with a silicon wafer as support during the process. At first, a 5 µm thick layer of polyimide resin (Pyralin PI 2611, HD Microsystems, Bad Homburg, Germany) was spun onto a silicon wafer that served as a support structure during most of the process. The polyimide was cured in an oven (PB 6-2, YES) under nitrogen atmosphere. An aluminum etching mask was deposited and structured with wet etching to define electrode sites on the backside. A second polyimide layer of 5 µm, which in the end serves as the backside insulation and protection layer, was spun on top of the aluminum and cured as

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described above. The first metallization layer (200 nm platinum, 5 nm titanium) forming the electrode sites on the backside was deposited by sputtering (L 420 SP, Leybold) and structured by lift-off technique. The second metallization layer (5 nm titanium, 300 nm gold, 5 nm titanium) for interconnect lines on the backside was sputter deposited and structured. Then the middle layer of polyimide with a thickness of 5 µm was spun on. In this layer via holes were structured with reactive ion etching (RIE) in a STS 320 PC generator (Surface Technology Systems). These via holes are used for the connection of the backside metallization to the contact pads which were formed on the front. Then the metallization on the front was structured as described above for the backside but this time the other way round, first the metallization layer (5 nm titanium, 300 nm gold) for connection pads and interconnect lines, then the metallization (5 nm titanium and 200 nm platinum), forming the electrode sites. A last polyimide layer of 5 µm was spun on for the top insulation and mechanical protection of the interconnect lines on the front. An aluminum etching mask was deposited and structured with wet etching to define the outer geometry of the devices. In the next step, RIE was used to separate the devices by etching the outer shapes down to the aluminum layer which defined the electrode sites on the back. Then a second aluminum etching mask was deposited and structured with wet etching to open the electrode sites and connection pads on the front of the devices, which was done again with RIE. After this. the whole polyimide foil was removed from the supporting wafer which was done mechanically. Finally, the electrode sites on the back were opened using RIE and the shaft electrodes were separated and cleaned.

B. Electrode optimization and characterization

A sample of the electrodes from the front and backside of the devices has been electrochemically characterized with impedance spectroscopy in physiologic saline solution (0.9 % NaCl) at room temperature with an impedance gain/phase analyzer (Solartron 1260, Farnborough, UK) and an electrochemical interface (Solartron 1287, Farnborough, UK). The impedance spectra have been measured with a three electrode setup (device under test / platinum counter electrode / Ag/AgCl reference electrode) at an amplitude of 10 mV and frequencies between 10 Hz and 100 kHz.

The electrodes from the front side have been treated with voltage pulses (500 pulses, 5 V, 10 ms) to remove possible residues from the electrode surfaces. The electrodes from the back side remained untreated.

Platinum black was deposited on the front side electrodes 3, 5, and 7 with the following method: 5 g H_2PtCl_6 was dissolved in 357 ml ultra pure water. Subsequently, 71.4 mg $Pb(NO_3)_2$ were added (Merck KGaA, Darmstadt, Germany). Voltage-controlled electroplating was carried out, using a platinum counter electrode and an Ag/AgCl reference electrode, connected to custom-made potentiostat. A DC signal was applied between counter electrode (anode) and starting layer of electrode structure (cathode) for a specific time period. During the deposition process, ultra sound was applied to the electrolyte in order to immediately remove bad adhesive platinum black particles from the electrode structure.

Impedance spectroscopy has been performed before and after pulse treatment and after electroplating.

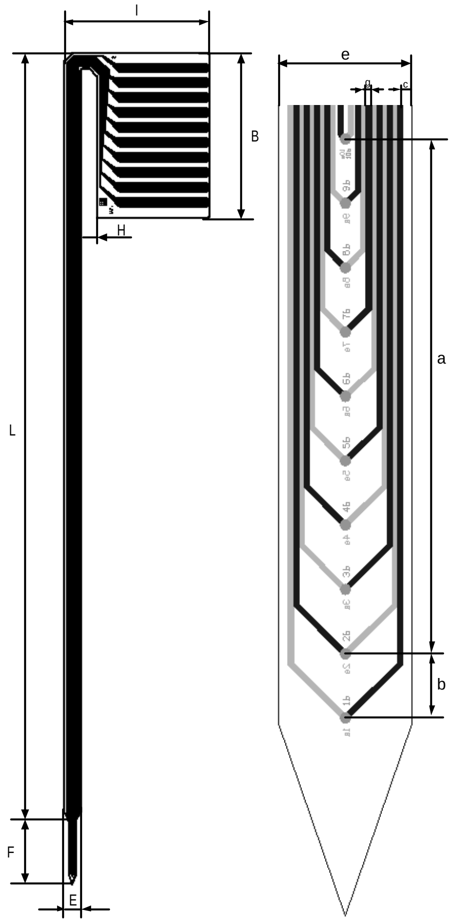

Fig. 2: Design of double-sided shaft electrodes with integrated interconnects and connector pads (left). Different colors indicate different layers. Right: detailed view of “shaft 20”.

C. Recordings from acute implantation

For the acute *in vivo* measurements, the optic nerve of a rat was used. For this purpose, the animal was anaesthetized with a solution of 7% chloral hydrate in 0.9% saline (0.6 ml per 100 g body weight). The optic nerve of an adult male Sprague-Dawley rat was exposed by making an incision above the eye, cutting the ocular muscles and removing the lachrymal glands. The bulbus was pulled gently in order to gain access to the optic nerve, and the shaft electrode was inserted through a thin incision made parallel to the optic nerve. Finally, the bulbus was returned to its natural position, and the skin above the eye was sutured.

Measurements were performed in a grounded Faraday cage in order to reduce noise, with a band-pass from 100 Hz to

5 kHz and a sample rate of 10 kHz. A commercial flashlight was used for optical stimulation. Recordings were performed on eight channels corresponding to the electrodes 1 to 8. The electrodes 16 to 20 were used as counter electrodes. The ISO-DAM-8 (WORLD PRECISION INSTRUMENTS, Sarasota, Florida) served as an amplifier. The discharge of the flashlight elicited a sharp pulse with a width of less than 1 ms in the recordings.

III. RESULTS

A. Polyimide-based shaft electrodes

First prototypes of the shaft electrodes were fabricated proving the feasibility of the process (Table 1, Fig. 2). They were realized with a total thickness of 15 µm with 10 electrodes on each side. Integrated ribbon cables interconnect the electrode area with a connection pad area. All interconnection pads were arranged on the front side. The array fits to commercially available "zero insertion force" plugs for flex tape applications. The devices showed well aligned, accurate shapes, a sharp tip geometry, steep edges, and a smooth surface (Fig. 3 and Fig, 4). The electrode sites were well aligned upon each other at electrode pitches of 125 µm.

TABLE I
SPECIFICATIONS OF DOUBLE SIDED SHAFT ELECTORDES

Dimension [µm]		shaft 20
device length	L	26,270
connector separation	H	500
connector length	B	10,500
interconnect width	E	900
insertion length	F	1950
connector width	I	5,590
insertion width	e	260
distance to edge	c	20
metallization lines	g	10
electrode metal	D	20
electrode opening	d	10
electrode area	-	78.5 µm²
electrode array length	a	1000
electrode pitch	b	125
number of electrodes per side	-	10

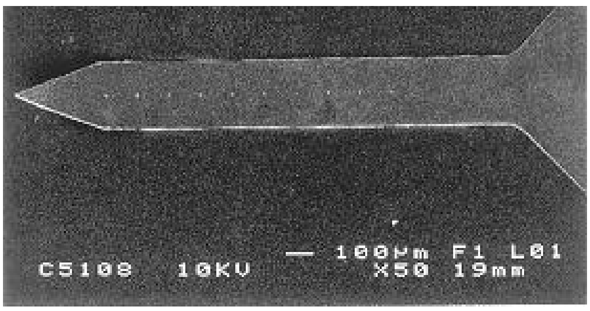

Fig. 3: View of a "shaft 20". Scanning electron microscopy.

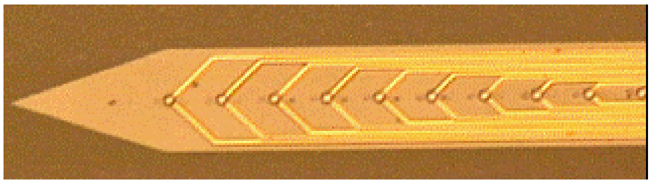

Fig 4. View of a "shaft 20" device. The thickness of the complete device comprises 15 µm, light microscopy.

B. Electrode optimization and characterization

The electrical impedance spectroscopy delivered high impedance values from samples of the electrodes from the front and backside, respectively (4 MΩ with a phase angle of –63 ° at 1 kHz). After pulse treatment, the electrode impedance decreased to values between 1.6 MΩ and 3.5 MΩ.

Well adherent, uniform layers of platinum black were achieved in the electroplating process by application of 0.5 V for a duration of 30 sec. This process step essentially reduced the electrode impedance below 100 kΩ with an phase angle of –37 ° at 1 kHz.

C. Recordings from acute implantation

Recordings have been performed on eight channels (Fig. 5). Despite the use of a Faraday cage and other shielding measures, electrical noise of 50 Hz and its multiples was still evident. Noise at 50 Hz was particularly high at electrodes 1 and 5. Different nervous activity was recorded at the electrodes, depending on their position within the optic nerve. Whereas almost no response could be recorded at electrodes 5 and 7, a clear activity could be recorded at electrodes 1, 2, 4 and 6. Although many optic nerve axons may have been damaged by the insertion of the shaft electrode, the number of intact axons are sufficient to elicit electrical activity. The different shape of the recordings on the several channels indicates that it is no external artifact, but that it is real response to the optical stimulation.

IV. DISCUSSION

Double sided, polyimide-based shaft electrodes were fabricated and tested in acute implantation. Recordings were obtained from the optic nerve in different quality. At some electrodes the signal to noise ration was quite good to record neuronal activity. At other electrodes, the (50 Hz) noise level was quite large indicating a high impedance (e.g. electrodes 1 and 5). All electrodes should be electroplated in further experiments to ensure a sufficiently large signal to noise ratio for the bioelectrical signal.

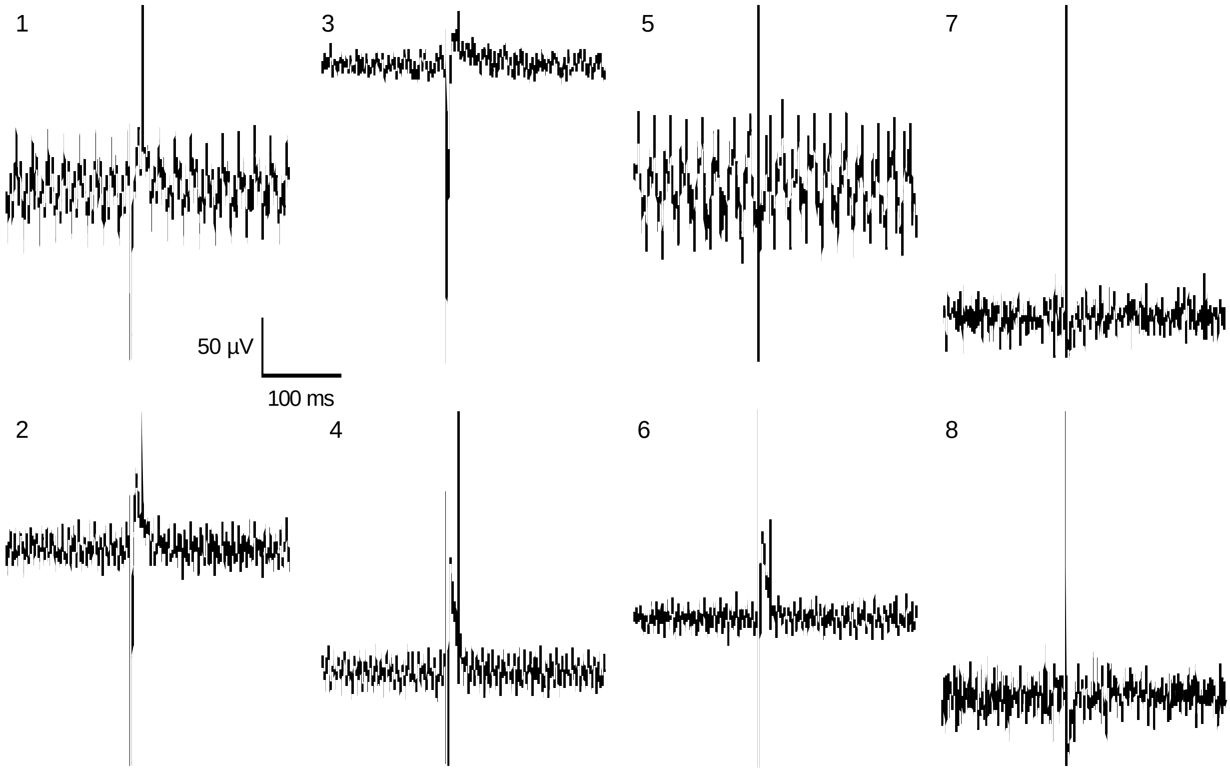

Fig. 5: Recordings from a shaft electrode inserted in the optic nerve of the rat. Even numbers indicate electrodes on the front side, odd numbers indicate electrodes on the back side.

V. Conclusion

A process technology to fabricate flexible, double-sided shaft electrodes with integrated cables was presented.. The devices showed steep edges, a smooth electrode and substrate surface. Recordings from the optic nerve were obtained via the electrodes. Electroplating the electrodes with e.g. platinum black will decrease their impedance and lead to a better signal to noise ratio.

The double-sided electrode arrangements have been envisioned for implantations in regions wherein high spatial selectivity should be obtained with minimal insertion and implantation trauma. In combination with hybrid integration (e.g. [4]) of microelectronic circuitry for recording, stimulation and telemetric links, the presented electrodes may become a key component in BIOMEMS for neural prostheses and biohybrid systems.

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